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ABSTRACT

Problems of cost stall substantial implementation of computer-assisted instruction, (CAI) particularly for dispersed populations. This paper examines the problems inherent in providing CAI to scattered groups so that accurate estimates of the costs of different technologies (including satellites) which could deliver CAI to dispersed populations can be made and so that, on the basis of these costs, educators can make decisions about the allocation of their resources. The paper first outlines a CAI system capable of reaching dispersed populations without excessive costs (i.e., the system requires only 110 bits per second communications capability for each student terminal). This makes the service economically feasible. Next, models of several communications alternatives for the system are provided. The results of this modeling constitute approximate minimum cost communication designs for many configurations of population dispersal. Finally, some basic economic trade-offs and implementation alternatives are described which are relevant to educators who must decide whether or not to use CAI for certain student populations. (Author/PB)

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COMPUTER-ASSISTED INSTRUCTION FOR DISPERSED POPULATIONS:

SYSTEM COST MODELS

BY

JOHN BALL AND DEAN JAMISON

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COMPUTER-ASSISTED INSTRUCTION FOR DISPERSED POPULATIONS: SYSTEM COST MODELS

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COMPUTER-ASSISTED INSTRUCTION FOR DISPERSED POPULATIONS: SYSTEM COST MODELS[1]

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I. Introduction

In recent years advances in communication and education have made possible two very attractive classes of educational technology. The first of these is the development of broadcast technology by which radio or television programs originating at a single point can be distributed to, potentially, many millions of educational users. The second and much more recent of these advances centers around potential use of a computing system to provide interactive instruction. By tailoring curriculum to an individual's needs and providing immediate and accurate feedback, instruction via computer offers great potential, perhaps greater than the broadcast media. Computer-assisted instruction (CAI) is an increasingly familiar technology at academic research institutions and in the journals. Problems of cost and availability have, however, stalled efforts at implementation on any substantial scale. For this reason, in our work on CAI development at Stanford University's Institute for Mathematical Studies in the Social Sciences (IMSSS), we have paid increasing attention to the basic economic trade-offs involved and to the problems of implementation facing a school administration that wants to utilize CAI.

Provision of CAI or CMI (computer-managed instruction) of any sophistication implies the need for one or a few large central computing facilities--at least with presently available technology. Thus, if rural regions or dispersed populations are to be able to share in the potential of interactive educational technologies, an extensive communication system is required. In a previous paper--Jamison, Suppes, and Butler (1970)--we examined the basic economics of providing CAI in urban areas.[3] Since all student terminals can, under urban conditions, be located reasonably close to the central computation facility, cost and implementation problems are reduced. In this present paper we examine the somewhat more difficult problem of providing CAI to dispersed populations. Our work in developing cost models for distribution of CAI to dispersed populations has been part of a project funded by the Bureau of Education for the Handicapped, U.S. Office of Education, to develop CAI materials for deaf students. The deaf constitute a rather highly dispersed population within the United States and problems of communication to support a CAI system for them are paradigmatic for dispersed populations of other types. Other dispersed populations include American Indians, Americans whose first language is Spanish, medical doctors, students at isolated rural schools, and migrant workers (who have the additional communication difficulty of being mobile).

Experience has indicated that the cost and complexity of terrestrial communication systems for CAI are often a stumbling block to provision of service in rural areas; establishing and servicing circuits in remote areas is difficult. Independent telephone companies do not always provide data services or equipment. There are areas in the

United States which cannot be reached by this type of CAI service due to lack of telephone company facilities. It could be argued that because it is more difficult to supply these dispersed populations with CAI than to supply more concentrated populations, the dispersed populations should be left until last. Our view is that, at the very least, we should examine with care the costs of different technologies that could provide CAI service to dispersed populations (including satellite communication), and on the basis of these costs let the decision makers responsible for providing education to these groups make decisions about how their resources should be allocated.

In this paper we outline a CAI system capable of reaching dispersed populations without excessive communication costs (i.e., the system requires only about 110 bits per second communications capability for each student terminal).[4] This low communication requirement makes service for dispersed populations economically feasible. Then we present models of several communications alternatives for the system. We expect that these procedures of system modeling and design trade-off will play an increasingly important role in education. The results of this modeling constitute approximate minimum cost communication designs for many configurations of population dispersal. Finally we describe some of the basic economic trade-offs and implementation alternatives relevant to educators who must decide whether or not to use CAI for certain student populations.

II. Central Facility and Student Terminal Cost Model

CAI systems are commercially available for under $50,000. They support a few fixed courses on 8 to 20 local terminals and provide daily progress statistics to the teachers. These systems are of considerable interest for a number of uses and will perhaps assume a larger role in our educational processes in the future. Jamison, Suppes, and Butler (1970) provide a cost analysis for systems of this sort. However, the cost of a large and versatile system that is capable of research use and supporting hundreds of terminals will be our focus in this section. Our costs are based on a system modeled after the one presently used for research and operations at IMSSS, but dedicated to CAI terminal service full time. Using modern versions of our present equipment designs we estimate that such a system could support 1,000 users simultaneously. Assuming that only 70% of the terminals would be on-line at once, the system could handle 1,300 terminals.

Three cost categories--capital equipment, design and construction, and continuing operations--will be discussed in this section. These cost categories apply to the central computation facility and terminals; Section III discusses the data communication cost models that are the focus of this paper.

A. Capital Equipment

The system would be modeled along the lines of the IMSSS system except that it would be newer and larger. All of the equipment can be purchased or built today.

Table 1 shows capital components and their costs; without student terminals the capital cost is $1,720,000. The complete system including

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Insert Table 1 about here

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student terminals would cost $3,025,000. Since prices for most computer equipment have been declining recently, these figures represent an approximation to the cost of the present IMSSS system, which would have the capacity to run approximately 1,300 student terminals if it were used solely for CAI.

B. Design and Construction

Although it is not quite as definitive as the capital equipment list, this estimate is reasonably accurate. The design and construction category covers the 1.5 year lead time that would be necessary to make this system operational. The staff would comprise:

1 system manager,

4 system programmers,

4 design engineers,

6 technicians,

4 draftsmen,

part-time specialists,

secretarial assistance, and

accounting, purchasing, and receiving personnel.

The cost of their time would total about $550,000.

It is also necessary to include one year's space rental in this category. The system and staff will require about 7,000 square feet with

TABLE 1

Equipment Costs of CAI System Components for 1,300 Terminals

(Excluding Communications)

Component	Description	Cost
Core Memory System	256K words on-line plus two working spare 32K boxes. Including individual 6-port interfaces and port connectors.	$ 330,000
Central Processor	Program compatible with the PDP-10 and including a pager.	300,000
Drum	4.5 million word storage on three drums.	235,000
Disc	Two separate systems each with about 50 million words of storage.	240,000
I/O Multiplexer	Includes a multiplex computer and a special purpose multiplexer.	225,000
Data Communication	Local test and patch facilities and test equipment. (See Section IV for remote equipment and operating costs.)	100,000
Terminals	1,450 student terminals @ $900	1,305,000
	10 system terminals @ $4,000	40,000
Miscellaneous	Magnetic tape drives,	100,000
	Line printers,	50,000
	Disc packs, magnetic tapes, terminal spare parts, storage facilities, etc.	100,000
TOTAL		$3,007,000

about 3,500 square feet requiring special raised floors and air conditioning. An estimate of this cost is $50,000 for remodeling and $5 per square foot lease cost, for a total of $85,000. Thus our estimate of the total cost for design and construction of this system is $635,000 (= $550,000 + $85,000).

C. Continuing Operation

It would seem appropriate to keep this system in operation 24 hours a day to achieve the minimum cost per terminal hour. Our present system operates for CAI use from 5:00 a.m. to 10:00 p.m. to cover both east coast and west coast elementary schools and college evening schools. There is a continuing struggle for system access during the remaining hours for system software development, hardware development, hardware maintenance, and users with larger programs.

A system with 1,000 simultaneous student users could operate with the following (without curriculum development, maintenance, or research staff):

supervisor and 6 operators,
supervisor and 5 curriculum coordinators,
4 system engineers and 1 design engineer,
supervisor and 12 data communication technicians,
center manager, and
secretarial assistance.

In addition, allowance must be made for

accounting, purchasing, receiving, supplies and operating expenses, telephone service, building maintenance, and staff benefits.

A reasonable estimate of these costs would be $750,000 per year, to which we must add about $35,000 per year for rental of space (approximately 7,000 square feet) for a total of $785,000 per year.

D. Annual Costs

In order to get annual cost estimates for the system it is necessary to add to the cost of continuing operation some "annualized" version of the initial costs for capital equipment, design, and construction. The standard way of presenting annualized costs in terms of initial cost is by way of the following formula:

$$\text{annualized cost} = \frac{r(1 + r)^{\ell}}{(1 + r)^{\ell} - 1} \times \text{initial cost} ,$$

where r = cost of capital (interest rate), and

ℓ = useful life of the equipment.

We assume a cost of capital of 10% and a (conservative) equipment life estimate of 8 years; in this case the annualized cost will be .19 times the initial cost of $3,007,000 for equipment plus $635,000 for design and construction. Thus the annualized initial cost is $3,642,000 × .19, or $692,000 per year. To this we add the annual operating costs of $785,000 to obtain a total cost of $1,477,000 per year for a 1,300 terminal system, excluding communication costs. (No allowance for overhead charges or profit margins appear in these figures.)

It should be remembered that the operating system described here would value from support from one or more research systems such as the existing IMSSS system. Curriculum development to expand and improve the existing curriculum menu would also be worthwhile. There may also be a demand, in a few years, to alter the scope of the system by adding visual presentation capability to the terminals. The CAI system design described here is really a large-scale general purpose computing system; as such, it would readily evolve with new curricular materials and research ideas.

III. Data Communication Cost Models

This section will develop comparative cost models for alternative communication systems for a CAI network serving a dispersed population. The communication process to be modeled is shown in Figure 1. The centralized computing system and low data rate terminals are parameters

Insert Figure 1 about here

determined from the system description in Section II. Our analysis here will not deal with large clusters of terminals located very close to the central computer; our purpose is to ascertain the cost of serving sparse concentrations of terminals located several hundred miles or more away from the central computer facility. We develop cost models based on use of communication satellites, as well as the surface phone network, for provision of the communication capacity.

The satellite communication system shown in Figure 2 follows easily from the model shown in Figure 1. The satellite is assumed to have a beam width sufficient to cover the area of interest, possibly the entire

Insert Figure 2 about here

continental United States, and sufficient power to service the remote sites. Appropriate cost for these assumptions will be included in our

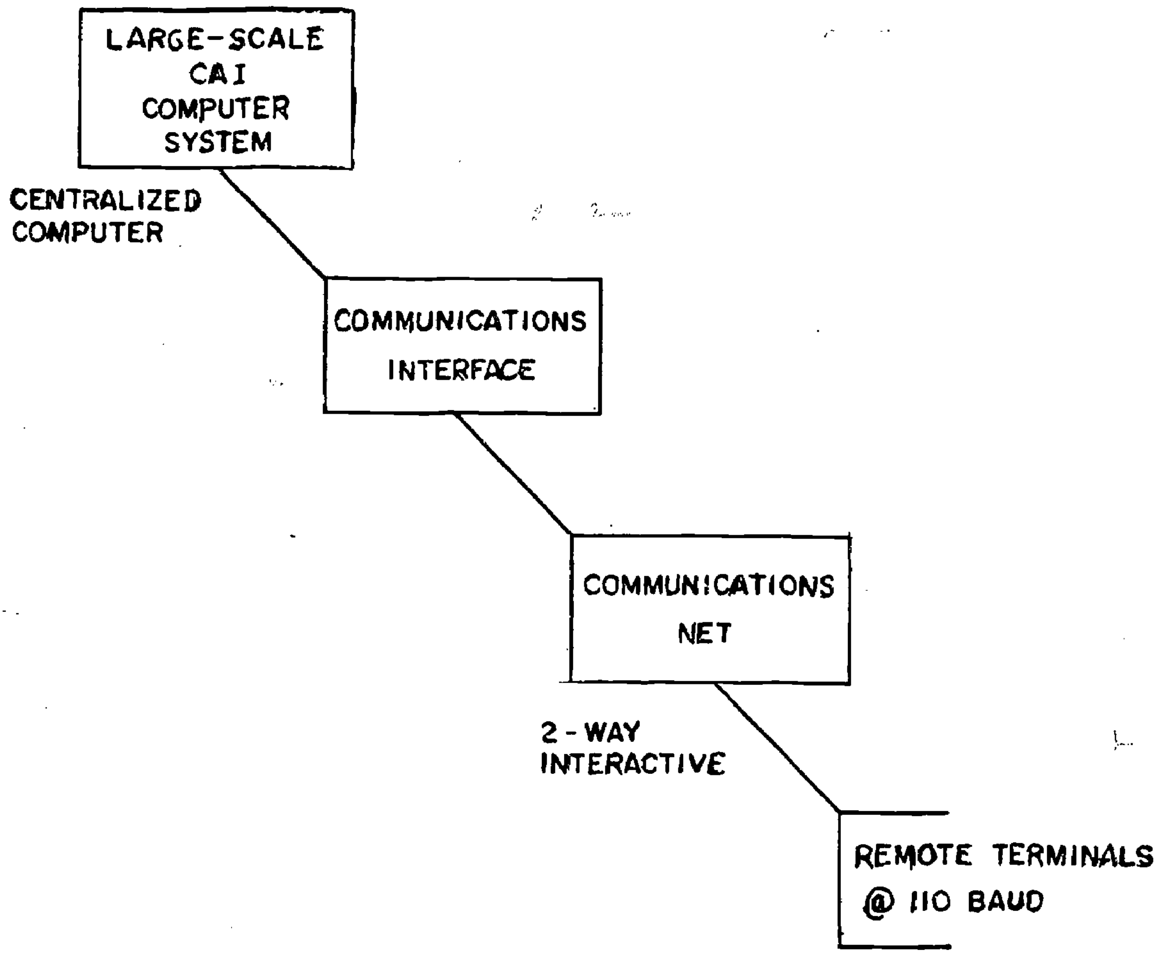

Fig. 1. Computer-assisted instruction communication model.

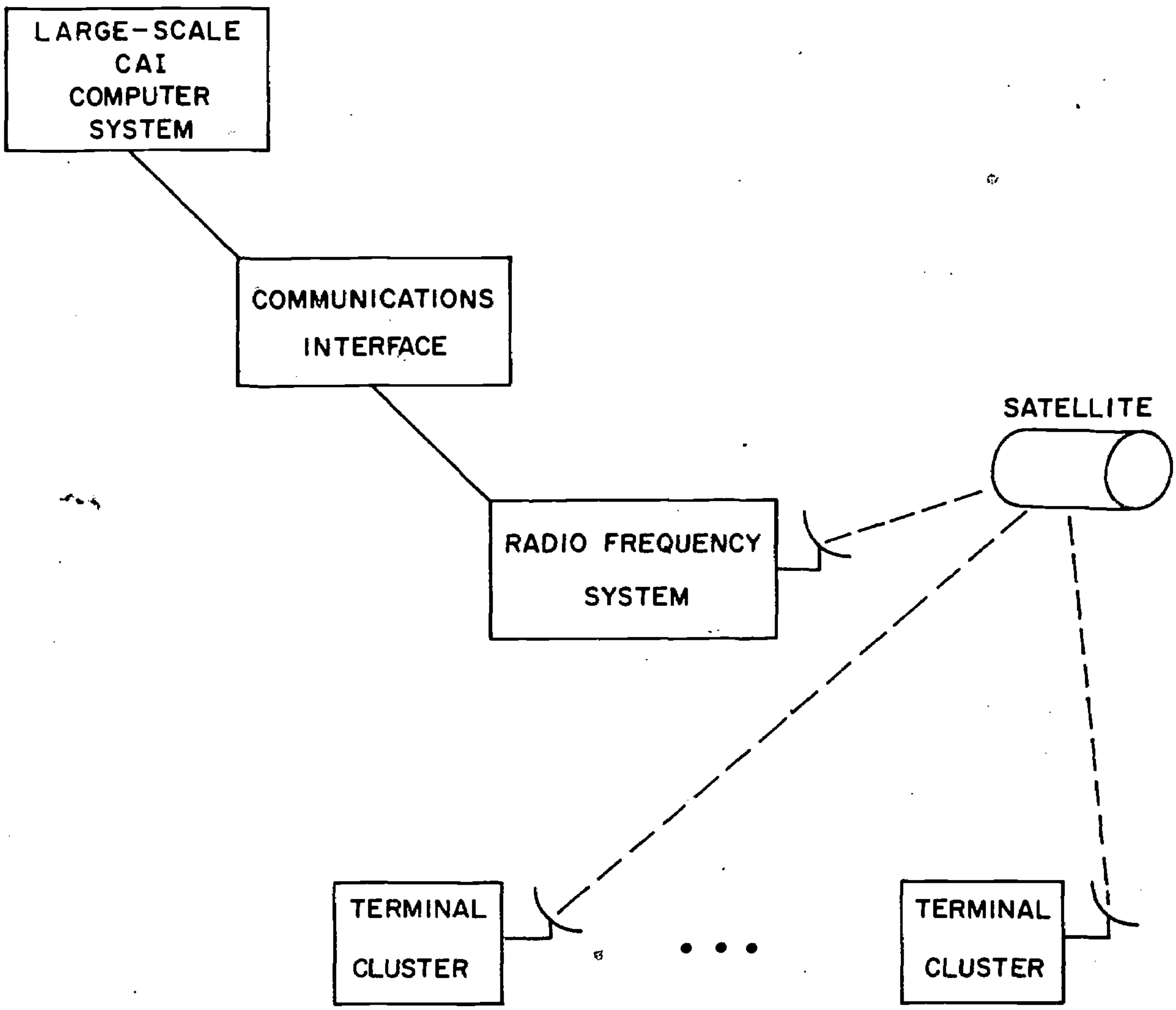

Fig. 2. Computer-assisted instruction satellite communication network.

analysis. Such a satellite system would be relatively independent of placement of remote sites.

A system using telephone lines in its communication net cannot be sketched so easily. Telephone line costs are governed, today, by tariff rate schedules. Several variables in these schedules make it necessary to consider differing forms of the communication net. Also, the bandwidth constraints on phone lines force us to start new circuits as the capacity of previous circuits are reached. Line costs follow a flat rate within each state. Lines which cross state boundaries have a declining rate schedule based on mileage. Charges are also made for end termination and conditioning of the lines.

In the first subsection of this part, cost models for five separate telephone communication systems are developed. The next subsection develops a satellite system cost model and the third subsection contains tables that present the cost results parametrically. The final subsection discusses the results.

A. Telephone Line Communication Models

Two styles of communication network designs will be considered here: the linear net and the cluster net. These two are representative of organizational extremes possible with telephone nets. The linear net is shown in Figure 3. Each cluster of terminals serves

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Insert Figure 3 about here

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as a forwarding link for all terminals farther away from the central system. A speed constraint of 4800 baud[5] imposed on the fastest lines allows a maximum of about 68 terminals in each linear group. A cluster

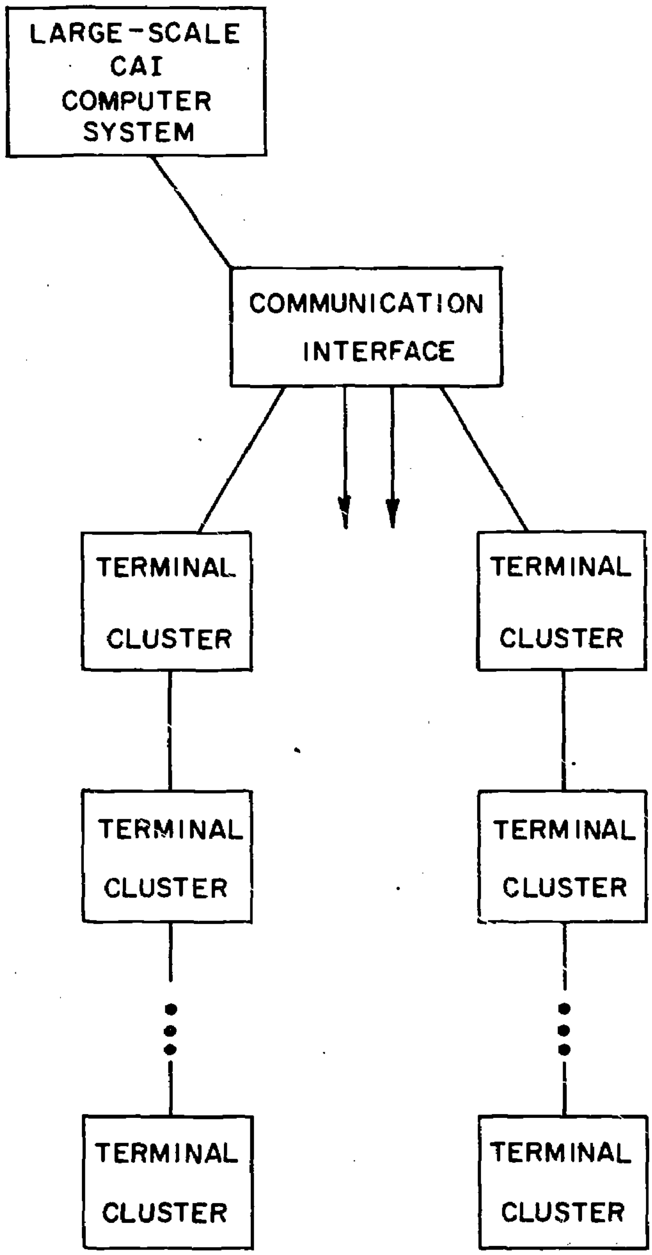

Fig. 3. Linear terrestrial communication network.

net design is shown in Figure 4. The size constraints are the same as the linear system since a 4800 baud line is used as the feeder to the

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Insert Figure 4 about here

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cluster. Distances to peripheral clusters may be assumed to be small, perhaps less than 25% of the feeder distance. Equipment in the cluster center will forward data to all clusters attached to it.

We will present distance variants within each cost model which can be adjusted to reflect either regional or national systems. The costs of a satellite system are almost independent of terminal placement. The cost models will compare a satellite communication system with five telephone networks as follows:

(1) A cluster system with a large interstate distance to the multiplex centers and smaller intrastate distances from centers to the small clusters.

(2) A cluster system located entirely within the computing center state, i.e., a large dense semilocal system.

(3) A linear system with a large interstate distance to the first cluster and smaller interstate distances among the remaining clusters. Every cluster in each of the linear nets must be in a different state. This forces a wide area terminal distribution.

(4) A linear system located entirely within the computing center state, i.e., a large dense local system.

(5) A linear system with a large interstate distance to the first cluster and smaller intrastate distances between the remaining clusters

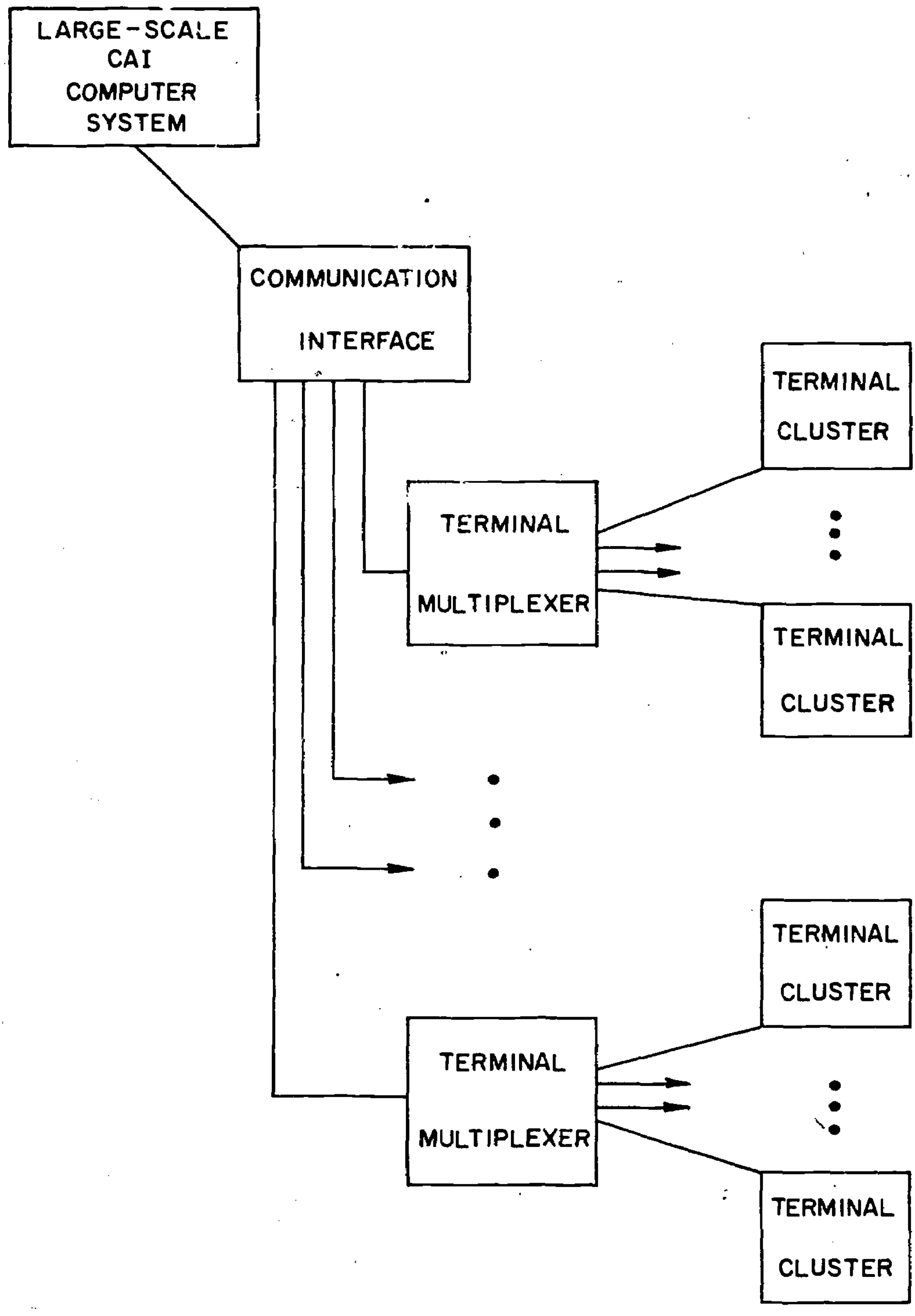

Fig. 4. Clustered terrestrial communication network.

in the linear network. All clusters are located in the same remote state. This produces a regional terminal distribution.

<u>Cluster systems</u>. For system (1) the basic design of each cluster is shown in Figure 5. The parameters of this system are shown in Table 2.

Insert Figure 5 about here

Insert Table 2 about here

Three cost terms will appear in the cost equation: multiplex system,[6] long lines, and local lines.

To develop the multiplex system cost the number of long lines, and hence the number of clusters, is needed:

$$\text{number of long lines} = \frac{T}{8(K + 1)} .$$

The annualized cost of capital, the annual maintenance cost, and the multiplex cost per cluster are the remaining factors in the multiplex system cost equation:

$$\text{multiplex system cost} = \frac{T}{8(K + 1)} M_t [0.1 + k(\ell,r)] .$$

The 0.1 factor represents a 10% annual maintenance charge for all installed electronics equipment. The annualizing formula, described before, is

$$k(\ell,r) = \frac{r(1 + r)^{\ell}}{(1 + r)^{\ell} - 1} .$$

If an equipment lifetime of eight years and a constant interest rate of 10% are used, then $k(8,.1) = .19$.

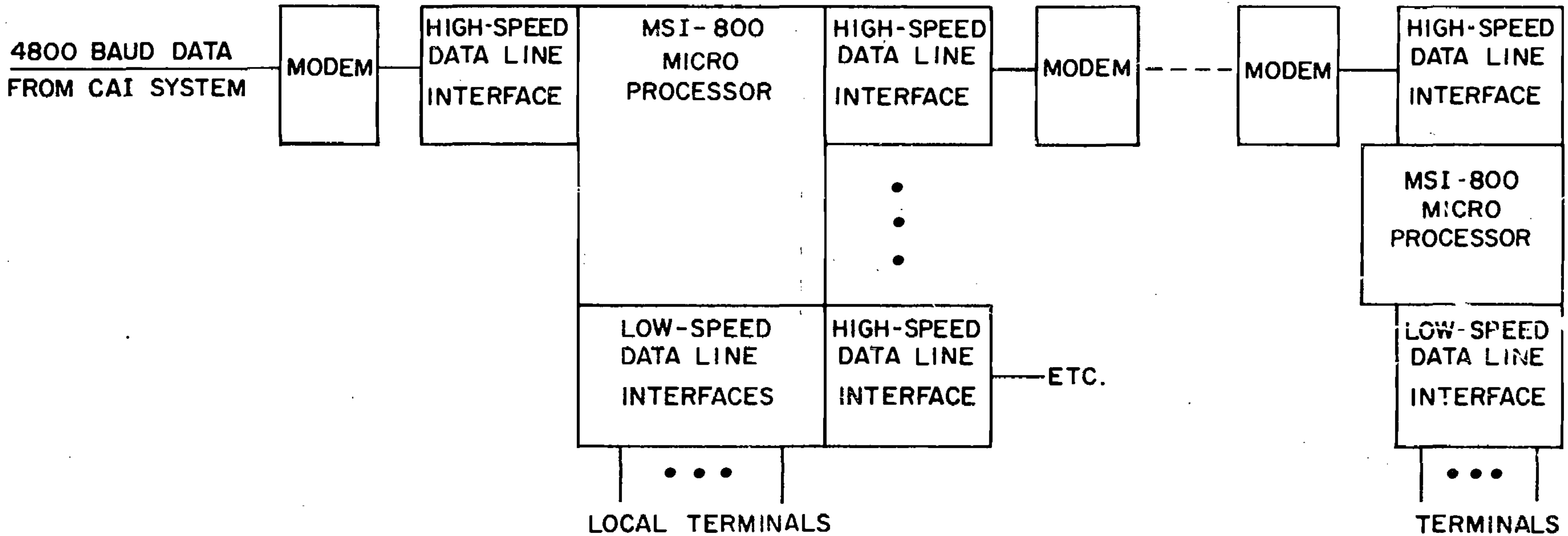

Fig. 5. Cluster multiplex system.

TABLE 2

Parameter Definitions for a Cluster Model of a CAI System[a]

Parameter	Definition
D	Long lines, mean distance.
d	Short lines, mean distance.
K	Number of clusters of 8 student terminals, each feeding into a multiplexing center ($4 \leq K \leq 8$).
T	Number of terminals in the whole system.
M_t	Cost of the multiplex equipment to supply each group of K clusters located remotely from the multiplexing center plus the one cluster assumed to be located at the center.
r	Annual interest rate (or social discount rate).
ℓ	Lifetime expected of capital equipment, in years.
COST	Annual cost for the telephone system.

[a]A cluster is defined as 8 terminals which can supply one CAI course to over 240 students each day.

The multiplex system cost, M_t, can be derived from the data in Table 3 and is given by, in thousands of dollars per year,

$$M_t = \frac{T}{8(K + 1)} (2.6K + 25.9)[0.1 + k(\ell,r)] .$$

Insert Table 3 about here

The second term in our cost equation represents the cost of renting long lines service from the telephone company. Long lines service is interstate in the model for system (1). Monthly costs by distance, in dollars, are derived from rate information as follows:

$$V = \begin{cases} 3.30\,D & 1 \leq D \leq 25 \text{ miles} \\ 82.50 + [2.31(D - 25)] & 26 \leq D \leq 100 \text{ miles} \\ 255.75 + [1.65(D - 100)] & 101 \leq D \leq 250 \text{ miles} \\ 503.25 + [1.15(D - 250)] & 251 \leq D \leq 500 \text{ miles} \\ 790.75 + [.825(D - 500)] & 501 \leq D . \end{cases}$$

To these mileage charges must be added conditioning charges of \$60 per month and termination charges of \$27.50 per month. Therefore, the cost equation for telephone long lines becomes

$$\text{interstate mileage charge} = \frac{T}{8(K + 1)} [87.50 + V(D)] .$$

For the short lines costs of system (1), intrastate rates are needed. Intrastate mileage charge is a constant function of mileage which varies from state to state but approximates \$4 per mile. For intrastate mileage charges we use, therefore, a monthly cost of \$4d, where d is the length of the intrastate link. To this must be added conditioning charges of \$91 per month and terminal charges as follows:

TABLE 3

Multiplex System Costs for a Cluster Communication Network[a]

Item	Number required	Unit cost	Cost
8 channel multiplex	K + 1	1.6	1.6(K + 1)
1200 baud modems[b]	2K	.5	1.0K
Central multiplex system	1	7.0	7.0
4800 baud modems[b]	2	5.4	10.8
Central CAI system line unit	1	2.5	2.5
Assembly and testing			4.0
			$M_t = 2.6K + 25.9$

[a]Costs are given in thousands of dollars.

[b]A modem changes the digital signals coming to or from the various terminals into signals suitable for transmission on a phone line. Modems capable of transmitting information at faster rates are substantially more expensive.

$$T(d) = \text{terminal charges} = \begin{cases} \$44, & D > 25 \text{ miles} \\ \$22, & D \leq 25 \text{ miles} . \end{cases}$$

The total cost equation for telephone short lines then becomes:

$$\text{intrastate mileage charge} = \frac{T}{8(K + 1)} K(4d + T(d) + 91) .$$

The total communication cost equation for system (1) is the sum of the multiplexing costs and inter- and intrastate line costs. These costs, in thousands of dollars per year, are given by:

$$\begin{aligned} COST_1 &= \frac{T}{8(K + 1)} (2.6K + 25.9)[0.1 + k(\ell,r)] \\ &+ \frac{T}{8(K + 1)} \frac{12}{1000} (27.50 + 60 + V(D)) \\ &+ \frac{T}{8(K + 1)} \frac{12K}{1000} (4d + T(d) + 91) . \end{aligned}$$

When the entire system is located within the state of the central computer, intrastate line costs must be used for both D and d. This gives us the annual cost of system (2) as:

$$\begin{aligned} COST_2 &= \frac{T}{8(K + 1)} (2.6K + 25.9)[0.1 + k(\ell,r)] \\ &+ \frac{T}{8(K + 1)} \frac{12}{1000} (4D + T(D) + 91) \\ &+ \frac{T}{8(K + 1)} \frac{12K}{1000} (4d + T(d) + 91) . \end{aligned}$$

Linear systems. The linear configuration of systems (3), (4), and (5) can be seen in Figure 6. The linear circuit begins at the

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Insert Figure 6 about here

CAI computer and connects each group of 8 terminals in turn, dropping 8 terminals and forwarding the rest. As the number of terminals on the

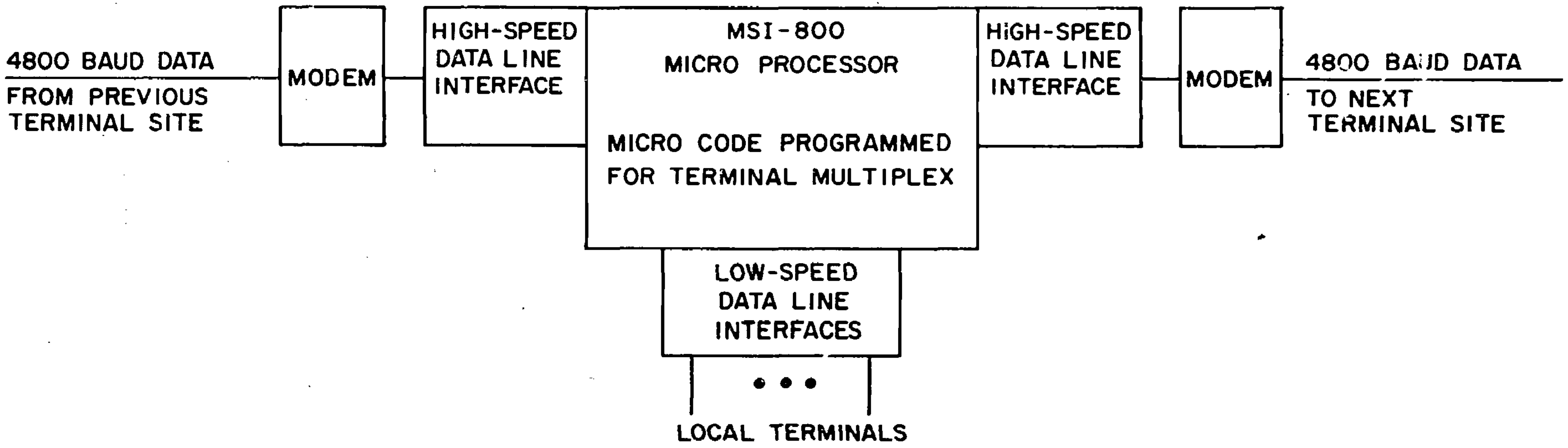

Fig. 6. Linear multiplex system.

line decreases, the modem speed can be correspondingly reduced. For all three of the linear systems, a distance of D miles to the first terminal group and a constant d miles between each of the remaining groups is used for our cost derivation. The systems differ in the extent to which interstate lines are involved.

Just as before, the total number of circuits needed (equal to the number of strings of terminal clusters) can be expressed by:

$$\text{number of circuits} = \frac{T}{8(K+1)}, \qquad 4 \leq K \leq 8 .$$

To compute M_t, the terminal capacity of various modems must be considered. A 4800 baud modem can handle 68 terminals; a 2400 baud modem, 32 terminals; and a 1200 baud modem, 8 terminals. The number of modems needed for $K = 4, 5, 6, 7,$ and 8 can be counted by drawing the circuits. The results are as follows:

	4800 baud		2400 baud		1200 baud
K = 4	2	+	6	+	2
K = 5	4	+	6	+	2
K = 6	6	+	6	+	2
K = 7	8	+	6	+	2
K = 8	10	+	6	+	2

This data allows the multiplex cost shown in Table 4 to be derived. Except for the last group in each linear group of terminals, all multiplex systems are assumed to be of equal cost.

Insert Table 4 about here

TABLE 4

Multiplex System Cost of a Linear Communication Network[a]

Item	Number required	Unit cost	Cost
8 channel multiplex system (for the last terminal group)	1	1.6	1.6
1200 baud modems	2	.5	1.0
2400 baud modems	6	1.75	10.5
4800 baud modems	2(K + 1 - 4)	5.4	10.8(K - 3)
Multiplex system	K	10.0	10.0K
Line unit at CAI center			2.5
Assembly and testing			4.0
			M_t = 20.8K - 12.8

[a]Costs are given in thousands of dollars.

To compute the telephone charges for the linear model varying assumptions can be made. There are two mileage figures involved, the distance to the first group D and the other intergroup distances d. These will be costed here as

System (3) - all interstate,

System (4) - all intrastate, and

System (5) - D interstate and d intrastate.

Other combinations will give costs which can be interpolated from these cases.

For system (3) the telephone line costs are

$$\frac{T}{8(K+1)}\,(V(D) + KV(d))\ .$$

Adding the terminal and conditioning charges as before gives a monthly telephone line cost of

$$\frac{T}{8(K+1)}\,[V(D) + (K \times V(d)) + (K+1)(27.50 + 60)]$$

for system (3). Similarly, the telephone line costs for the other two systems are

$$\frac{T}{8(K+1)}\,[4D + 4Kd + (K+1)(44 + 91)]$$

for system (4), and

$$\frac{T}{8(K+1)}\,[V(D) + (27.50 + 60) + K(4d + 44 + 91)]$$

for system (5). Complete cost equations, in thousands of dollars per year, for systems (3), (4), and (5) can then be written as

$$\mathrm{COST}_{3,4,5} = \frac{T}{8(K+1)}\,(20.8K - 12.8)[0.1 + k(\ell,r)]$$

$$+ \frac{12}{1000}\,(\text{telephone line cost}),$$

where

$$\text{telephone line cost} = \begin{cases} \dfrac{T}{8(K+1)}\,[V(D) + KV(d) + (K+1)(27.50 + 60)]\,, \\ \qquad \text{for system (3) (all interstate)} \\ \dfrac{T}{8(K+1)}\,[4(D + Kd) + (K+1)(44 + 91)]\,, \\ \qquad \text{for system (4) (all intrastate)} \\ \dfrac{T}{8(K+1)}\,[V(D) + 27.50 + 60 + K(4d + 44 + 91)]\,, \\ \qquad \text{for system (5) (mixed),} \end{cases}$$

with $4 \leq K \leq 8$ and D, d > 25 miles. Cost of regional or national systems can be determined by adjusting D, d, and K. Data for various interesting combinations of these parameters, for all five telephone line oriented systems, will be presented after the satellite system cost model is developed.

B. Satellite Communication Model

Now we will look at the cost of a satellite communication system and compare that with the telephone line communication systems already described. Except for consideration of the satellite's coverage pattern, the system design shown in Figure 2 could be a suitable replacement for any of the telephone systems described in this section.

The following is a general cost equation for a satellite link.

$$\text{COST}_6 = V + \frac{T}{8} M_s[0.1 + k(\ell,r)] + \frac{T}{8} G[0.1 + k(\ell,r)] + S[0.1 + k(\ell,r)]\,,$$

where

$COST_6$ = annual communication and multiplexing system cost (in thousands of dollars),

M_s = cost of multiplex equipment per remote circuit,

V = annual cost of transponder use on the satellite (for large variations of T this may be $V(T/8)$, but assumed constant here),

G = cost of satellite ground station at a remote site,

S = cost of satellite ground station at the CAI center (for large variations of T this may be $S(T/8)$, but assumed constant here).

To compute the costs of a satellite communication system we first derive a figure for M_s as shown in Table 5. We can then put this figure into the cost equation and derive the following results:

$$COST_6 = V + [0.1 + k(\ell,r)][S + \frac{T}{8}(M_s + G)]$$

$$= V + [0.1 + k(\ell,r)][S + \frac{T}{8}(3.72 + G)] .$$

Insert Table 5 about here

Three unknowns remain:

V = satellite usage charges,

S = central RF[7] installation cost,

G = remote ground station costs.

Based on our current work with the ATS-3 satellite, unpublished papers of Dr. J. Jankey and Dr. James Potter, and conversation with others, we propose (1) to fix S at \$80,000, (2) to study three values

TABLE 5

Multiplexer System Cost for a Satellite Communication Network[a]

Item	Number required	Unit cost	Cost
8 channel multiplex system	1	1.6	1.6
1200 baud modems	2	.5	1.0
Line unit (shared among 12 sites)	1/12	2.5	.2
Mult[illegible]x computer (shared among 12 sites)	1/12	9.0	.75
Assembly and testing	1/12	2.0	.17
			M_s = 3.72

[a]Costs are given in thousands of dollars.

for G--\$1,000, \$3,000, and \$6,000--and (3) to allow V to vary from zero to \$500,000 per year. More detailed information on satellite and ground station costs for educational applications may be found in Dunn, Lusignan, and Parker (1972).

The satellite cost equation then can be represented as:

$$COST_6 = \begin{Bmatrix} 0 \\ 100 \\ 200 \\ 300 \\ 400 \\ 500 \end{Bmatrix} + [0.1 + k(\ell,r)][80 + \frac{T}{8}(3.72 + \begin{Bmatrix} 1 \\ 3 \\ 6 \end{Bmatrix})] .$$

C. Parametric Cost Summaries

Summarizing the types of systems to be costed, together with their variables, we have:

System (1), Cluster: D - interstate, d - intrastate, K, T

System (2), Cluster: D - intrastate, d - intrastate, K, T

System (3), Linear: D - interstate, d - interstate, K, T

System (4), Linear: D - intrastate, d - intrastate, K, T

System (5), Linear: D - interstate, d - intrastate, K, T

System (6), Satellite: V, G, T .

Tables 6 to 11 show various costs for each communication model considering different configurations within the model. The cost of capital and an equipment life of 10% and 8 years is fixed in these tables.

Insert Tables 6 to 11 about here

As an example of how these tables might be used to obtain minimum cost configurations, consider the problem of supplying CAI to a population

TABLE 6

Cost of Communication System 1: Clustered Organization with Interstate/Intrastate Mix[a]

D = interstate distance	d = intrastate distance	K[b]		
		4	6	8
(A. 300 terminals)				
2,000				
	200	606	561	536
	100	461	406	376
	50	389	329	296
1,500				
	200	569	535	516
	100	424	380	355
	50	352	302	275
500				
	200	495	482	475
	100	350	327	314
	50	278	249	234
(B. 1,000 terminals)				
2,000				
	200	2021	1872	1789
	100	1539	1356	1254
	50	1298	1098	986
1,500				
	200	1897	1784	1721
	100	1415	1267	1185
	50	1174	1009	918
1,000				
	200	1773	1695	1652
	100	1291	1179	1116
	50	1051	921	849
500				
	200	1649	1607	1583
	100	1168	1091	1048
	50	927	832	780

[a]The costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]K is the number of clusters of 8 terminals each connected to each long line.

TABLE 7

Cost of Communication System 2: Cluster Organization
Single State Coverage[a]

D = interstate distance[b]	d = intrastate distance	K^c 4	6	8
(A. 300 terminals)				
500				
	200	608	563	538
	100	464	408	377
	50	392	331	297
300				
	200	536	511	498
	100	392	357	337
	50	319	279	257
(B. 1,000 terminals)				
500				
	200	2029	1878	1794
	100	1547	1362	1258
	50	1306	1103	991
300				
	200	1788	1706	1660
	100	1306	1189	1125
	50	1065	931	857

[a]The costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]The term "interstate" is used here to denote the long-line distance and "intrastate" to denote the short-line distance even though all communication is within one state.

[c]K is the number of clusters of 8 terminals each connected to each long line.

TABLE 8

Cost of Communication System 3: Linear Organization with All Interstate Connections[a]

D = interstate distance	d = intrastate distance	K^b		
		4	6	8
(A. 300 terminals)				
2,000				
	600	688	679	674
	400	617	602	595
	200	525	504	493
	100	465	440	427
	50	224	396	380
1,500				
	600	650	652	653
	400	579	576	574
	200	488	478	472
	100	428	414	406
	50	387	369	360
1,000				
	600	613	626	632
	400	542	549	553
	200	450	451	451
	100	391	387	385
	50	349	343	339
500				
	600	576	599	612
	400	505	523	533
	200	413	425	431
	100	354	361	365
	50	312	316	319

TABLE 8 (continued)

D = interstate distance	d = intrastate distance	K^b 4	6	8
(B. 1,000 terminals)				
2,000				
	600	2293	2263	2246
	400	2056	2009	1983
	200	1750	1681	1643
	100	1552	1469	1423
1,500				
	600	2169	2175	2178
	400	1932	1921	1914
	200	1626	1593	1574
	100	1428	1381	1354
	50	1290	1232	1200
1,000				
	600	2046	2086	2109
	400	1809	1832	1846
	200	1503	1504	1506
	100	1305	1292	1286
	50	1166	1144	1132
500				
	600	1922	1998	2040
	400	1685	1744	1777
	200	1379	1416	1437
	100	1181	1204	1217
	50	1042	1055	1063

[a]The costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]K is the number of clusters of 8 terminals each connected to each long line.

TABLE 9

Cost of Communication System 4: Linear Organization with Single State Coverage[a]

D = interstate distance[b]	d = intrastate distance	K^c		
		4	6	8
(A. 300 terminals)				
500				
	200	682	672	666
	100	537	517	505
	50	465	439	425
300				
	200	610	620	626
	100	465	465	465
	50	393	388	385
(B. 1,000 terminals)				
500				
	200	2274	2240	2221
	100	1792	1723	1685
	50	1551	1465	1418
300				
	200	2033	2067	2087
	100	1551	1551	1551
	50	1310	1293	1284

[a]The costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]The term "interstate" is used here to denote the long-line distance and "intrastate" to denote the short-line distance even though all communication is within one state.

[c]K is the number of clusters of 8 terminals each connected to each long line.

TABLE 10

Cost of Communication System 5: Linear Organization with Interstate/Intrastate Mix[a]

D = interstate distance	$\bar{d}$ = intrastate distance	K[b]		
		4	6	8
(A. 300 terminals)				
2,000				
	200	679	670	665
	100	535	515	504
	50	463	438	424
1,500				
	200	642	643	644
	100	498	488	483
	50	425	411	403
1,000				
	200	605	617	623
	100	461	462	463
	50	388	385	382
500				
	200	568	590	603
	100	424	425	442
	50	351	358	362

TABLE 10 (continued)

D = interstate distance	d = intrastate distance	K^b 4	6	8
(B. 1,000 terminals)				
2,000				
	200	2266	2234	2216
	100	1784	1718	1681
	50	1543	1459	1413
1,500				
	200	2142	2145	2147
	100	1660	1629	1612
	50	1419	1371	1344
1,000				
	200	2018	2057	2079
	100	1536	1541	1543
	50	1296	1283	1276
500				
	200	1895	1969	2010
	100	1413	1452	1474
	50	1172	1194	1207

[a]Costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]K is the number of clusters of 8 terminals each connected to each long line.

TABLE 11

Cost of Communication System 6: Satellite Distribution[a]

V^b	G^c		
	$1,000	$3,000	$6,000
(A. 300 terminals)			
0	73	95	127
100	173	195	227
300	373	395	427
500	573	595	627
(B. 1,000 terminals)			
0	192	264	272
100	292	364	472
300	492	564	672
500	692	764	872

[a]The costs given in the last three columns are annual costs in thousands of dollars; communication and multiplexing costs are included with capital costs annualized at an interest rate of 10% with an 8 year lifetime.

[b]V = annual cost in thousands of dollars of satellite transponder capital cost or use charges.

[c]G = cost of RF portion of each remote ground station.

whose average distance from the main computer center is 1,000 miles with a large number of clusters in each local group of clusters (K = 8). The intrastate distance (between each local cluster and its cluster center) is assumed to equal 50 miles. For 1,000 terminals, three of the configurations proposed here are relevant: cluster system (1), linear system (5), and the satellite system (6). For system (1) the cost (on a per-terminal basis) is $850 per year; for system (5) it is $1,276; for system (6) it is $564 under the conservative assumption that the ground station cost is $3,000 and the satellite usage cost is $300,000 per year. For this configuration, then, the satellite appears superior, as it would for any more dispersed population. In the very worst case of satellite costs, with $6,000 ground stations and a $500,000 annual satellite use cost, the cost of system (6) becomes $872, slightly more than that of system (1). Many other combinations of requirements can be similarly analyzed using these tables.

It may be of interest to continue this example to the point of computing total per-student-contact-hour costs of this communication configuration. At the end of Section II we estimated an annual cost for the system--including capital costs, operations, and maintenance-- of $1,477,000 per year for 1,300 terminals or $1,135 per terminal per year. To this must be added the $565 satellite communication costs for a total of $1,700 per terminal per year, or a little less than $150 per terminal per month, or $.85 per student contact hour, if we assume the optimistic goal of 2,000 hours of terminal use per year.

D. Conclusions

The foregoing communication models and their costs provide a basic cost analysis for providing interactive instructional materials to dispersed populations. Our approach has been to develop cost functions for alternative approaches to solving the communication problem for a CAI system. The values these cost functions take depend on many parameters. The advantage of this approach is that it enables one to ascertain quickly the approximate minimum cost configuration for any specification of the input parameters. More exact cost estimates would, of course, have to be generated at the time of preparation of the design of a specific system.[8]

The central numerical results of this section appeared in Tables 6 to 11. These tables show how annualized communication and multiplexing system costs vary as a function of the most critical parameters for three conceptually distinct approaches to the communications network--a clustered telephone line system (Tables 6 and 7), a linear telephone line system (Tables 8, 9, and 10), and a satellite-based system (Table 11). The different tables for the telephone-line-based systems show costs for different configurations of interstate and intrastate systems; this separation is necessarily due to the structure of the telephone tariff system.

Perhaps the most interesting result that emerges from this detailed analysis is the viability of a satellite-based system. For distances of the order of 500 miles there already appears to be a distinct cost advantage for the satellite approach; for distances of a thousand miles or more the advantage is quite pronounced. The importance of this finding depends on the form of the evolution of usage of the higher quality instruction made possible by interactive systems. If a large instructional computer system serves only its immediate geographical locale, it is clear that communications are best handled by telephone or cable systems. However, reliance on telephone line systems seems to preclude access to this form of high quality instruction for dispersed populations. Satellites will play a critical role for distribution of interactive instruction if national priorities indicate sensitivity to the needs of dispersed populations prior to the time when (probably 15 or 20 years hence) every geographical locality has its own interactive instructional system, or cable networks become versatile enough and sufficiently dense to serve as an interactive system communication network.

IV. Implementation Alternatives for CAI Networks

In the preceding sections we discussed the costs of alternative methods of providing CAI to dispersed populations. In this section we use these costs as an input to analysis of the basic economics of providing CAI, and the various implementation alternatives available.

A. Basic Economics of Providing CAI

The cost per operational CAI terminal in a school depends on many factors related to the basic organization of the system that provides the service. Later in this section, we will discuss a number of alternatives to that presented in this paper and reference more detailed costimates for them. First, however, we will make analyses of basic economic trade-offs, simply using conservative cost values based on estimates for the immediate future; we emphasize, however, that many components of these costs are declining.

Our basic cost assumption for this analysis is that for \$300 per month a Teletype terminal can be maintained in a typical school. This is deliberately highly conservative in order to allow a high margin for proctor costs and start-up inefficiencies. For a typical configuration with a 1,300-terminal system and a highly dispersed user population, Sections II and III indicate that the central facility, communication and multiplexing, and terminal costs would total \$125 to \$200 per month per terminal. This cost includes amortization of capital costs, use of the central computer system, communications, terminals, and operations and maintenance. It does not include any expenditures associated with making classroom space available, and it assumes the curriculum to already be available. We also assume that for 20 days per month an average of 25 student sessions per day are given at each Teletype. Thus, we assume 500 sessions per terminal per month at a cost of \$300, or \$.60 per session. We have observed high variance in the number of sessions per terminal per day obtained by different schools, and with effective scheduling it is feasible to obtain many more sessions per terminal per day than the 25 we assume. Some schools currently participating on the IMSSS network are obtaining utilization rates in the range of 35 to 40 sessions per terminal per day, suggesting the possibility of substantially lower costs per session than the \$.60 that we use. Also, we have assumed a six-hour school day; some residential schools for the deaf are using their terminals eight to ten hours per day, further increasing the number of sessions per terminal per day and further decreasing the cost per session. (In the preceding section we saw the possibility of reducing costs to \$.85 per student contact hour if usage can be pushed up to 2,000 hours per terminal per year.)

The decision of whether to provide CAI and how much CAI to provide depends not only on cost per session but on two other critical factors. First, of course, is the performance of CAI in raising student achievement. We will not examine data on CAI as an instructional tool in the paper but evaluations of IMSSS CAI curriculum can be found in Fletcher and Atkinson (1971), Suppes and Morningstar (1969), and elsewhere.[9] Second is the issue of <u>what must be given up in order to have CAI</u>. Given that budgets are inevitably constrained, the more CAI an administrator provides his students, the less he can provide of something else. A requirement of good administration is to make these trade-offs explicitly, both in terms of their cost and of their performance.

We will examine the situation in schools for the deaf, which currently use about half of the IMSSS student terminals, to illustrate how administrators might evaluate decisions about the use of CAI. Due to the low student-to-staff ratios, a larger fraction of resources goes into staff in schools for the deaf than in other schools, and the most feasible way of financing CAI is, therefore, through slight increases in the student-to-staff ratio. This method is the most feasible even if new resources for acquiring CAI come from outside the school; the new funds could have been allocated to lowering the ratio of students to staff rather than to providing CAI.

The trade-offs are summarized in the following equation adapted from Jamison (1971).

$$S^* = S + \left[\frac{(SW(1 - R)) + (C(N)S^2R)}{W - (C(N)SR)} \right]$$

where S^* is student-to-staff ratio after introduction to CAI,

S is student-to-staff ratio before introduction to CAI,

W is average annual salary of the instructional staff,

R is ratio of the post-CAI instructional cost per student to the pre-CAI cost, and

$C(N)$ is the cost of providing a student N sessions of CAI per year.

To estimate the "opportunity" cost of CAI, we solve the equation for S^* as a function of N (the number of CAI sessions per student per year) under the assumption that $R = 1$; i.e., we assume that CAI is introduced into schools for the deaf with no net increase or decrease in per-student instructional costs. To complete the calculation we need to know staff salaries and staff-to-student ratios and, to take an example, Table 12 displays this information for a number of different

Insert Table 12 about here

types of schools for the deaf. For the present illustration, we consider public day schools where the instructional staff salaries recently averaged $8,760 per year and the student-to-instruction-staff ratio was 4.5. We have, then, $S = 4.5$, $W = 8760$, $R = 1$, and, using the previous assumptions about costs, $C(N) = \$.60N$. The trade-off equation then becomes:

$$S^* = 4.5 + 12.15N/(8760 - 2.7N) .$$

TABLE 12

Salaries and Student-to-Staff Ratios in Schools for the Deaf for the 1968-69 School Year[a]

Type of school	Average annual salary of instructional staff	Ratio of students to instructional staff
Public Res. Schools	$7564	5.6
Private Res. Schools	6251	4.9
Public Day Schools	8760	4.5
Private Day Schools	6009	4.5
Public Day Classes	7721	3.9
Private Day Classes	7740	4.4

[a]Source: "Tabular Statement of American Schools and Classes for the Deaf, October 31, 1968," pp. 622-623 of the Directory of Services for the Deaf in the United States--American Annals of the Deaf, May, 1969.

Table 13 shows the student-to-staff ratio calculated from the above equation required to leave per-student instructional costs unaltered if each student has N CAI sessions per year for six values of N.

Insert Table 13 about here

It is evident from Table 13 that substantial amounts of CAI are feasible with only minor increases in student-to-staff ratios. For example, increasing the student to-staff ratio by 10%, from 4.5 to 4.95, would allow each child to have almost two CAI sessions daily (300 per year). The question facing the school administrator is whether the achievement gains resulting from this amount of CAI would counterbalance the achievement losses (if any) resulting from the slightly higher student-to-staff ratio.

B. Implementation Alternatives

In the preceding subsection, we outlined the basic economic considerations that would lie behind an administrative decision to utilize CAI in schools for the deaf. Now we will look at four possibilities for implementing CAI in schools for the deaf. Again, the schools for the deaf are simply used as an example of a typical dispersed population. These alternatives are equally possible for other groups of CAI users.

The first implementation alternative would consist of operational utilization of the IMSSS facility at Stanford, with the Stanford staff continuing in their present liaison, maintenance, and administrative roles. By the beginning of the 1973-74 school year, up to 300 terminals at various locations around the country could be made available enabling

TABLE 13

Student-to-Staff Ratio Required to Leave Per-Student Instructional Costs Constant with Implementation of CAI[a]

Number of CAI sessions per year	Student-to-instructional-staff ratio
0	4.5
100	4.64
200	4.79
300	4.95
500	5.30
1000	6.50

[a]The figures in this table assume a pre-CAI student-to-instructional-staff ratio of 4.5 and an average annual salary for the instructional staff of $8760. CAI is assumed to cost $.60 per 6 to 10 minute session.

5,000 to 10,000 deaf students to receive CAI as a standard part of their curriculum. The total cost per terminal per month would be between $250 and $400. This approach would have the advantage of being a direct extension of the services currently provided by Stanford and implementation problems would be minimized. Further, if curriculum development for the deaf were continued at Stanford, new and revised curriculum materials would be immediately available to all students in the network.

The second implementation alternative is identical to the first except that major administrative and operational responsibilities would be transferred to a school serving the deaf community. That school would be responsible for liaison with other schools, communications, Teletype maintenance, and administration of everything except the central computation facility at Stanford. The major attraction of this approach lies in the gradual but explicit transfer of technological expertise and control from the developers of a CAI system to its users.

A third alternative would be to implement the curriculums developed at Stanford with stand-alone mini-computer systems. The central processor on such systems requires no operator, and it is capable of serving 8 to 32 student terminals with relatively simple curriculum materials. Jamison, Suppes, and Butler (1970) provide a more detailed description and cost analysis for systems of this sort. Communication and multiplexing costs would be minimized by the small geographical dispersion of users. Per-terminal costs using this approach would be approximately two-thirds to three-fourths the costs involved in the first and second alternatives. However, the range of curriculums offered on mini-systems is more limited than in the first and second alternatives, and curriculum revision is far more difficult.

A fourth alternative, diametrically opposite to the third, would be to establish a large CAI center for the deaf that would be capable of simultaneously running 500 to 1,500 terminals such as the system described in this paper. Such a center would require nationwide communications. It could take full advantage of new and revised curriculums as they become available, and it could provide a wider range of curriculums than could a mini-system. As was shown in Section III, the use of communication satellites appears to be an economically attractive way of distributing CAI to a population as dispersed as that of deaf students. Per-terminal costs for a large-scale system such as this would probably fall between those of a mini-system and those of an expanded Stanford-based system. The difficulty with proceeding directly to this option is the substantial time lag between decision and implementation and the administrative difficulties inherent in expanding a small scale of operations to a very large one.

The above four alternatives summarize our current ideas for operationally implementing the results of presently available curriculum development efforts. These alternatives are not mutually exclusive. For example, it would be very natural to conceive of the second alternative evolving into the fourth. Similarly, a useful experiment to undertake would be to compare either the first or second alternative with the third, using different schools for the deaf in the two approaches.

The decision as to how to best educate any student population is always complex, and is usually made more difficult by budget constraints. One important factor in such decisions involves the relative effectiveness of different instructional methods for the particular students under consideration. We feel that it is also important for the educators who make such decisions to consider the relative costs of different instructional methods; we have tried to show in this paper that CAI is a viable alternative for instructing dispersed student populations, particularly with the possibility of a satellite communication network.

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Footnotes

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2. John Ball is the manager of the Computer Based Laboratory of IMSSS; Dean Jamison is a staff member of IMSSS, Assistant Professor of Management Science, Graduate School of Business, and Assistant Professor (by courtesy), School of Education, Stanford University. The authors are indebted to J. E. G. Ferraz and Joanne Leslie Jamison for valuable assistance with this paper.

3. Cost estimates for a very large-scale system (4,000 terminals) are given in Bitzer and Skaperdas (1969), and Stetten (1972) gives cost estimates for a system with 125 terminals. Both sets of estimates assume the terminals are clustered at the computer center or within 100 miles of it.

4. Detailed descriptions of earlier IMSSS CAI systems can be found in Suppes, Jerman, and Brian (1968), Suppes (1971), and Suppes and Morningstar (1972).

5. The term "baud" is a measure of communication capacity; a voice-grade line has a capacity of up to 9600 baud.

6. The multiplexing system assembles and disassembles signals in the communication line for direction to the individual terminals.

7. "RF" refers to the radio frequency electronic equipment.

8. To apply this model in a European setting, a different rate structure system would, of course, have to be substituted.

9. A survey of these evaluations, as well as a study of the impact of CAI on the distribution of achievement, may be found in Jamison, Fletcher, Suppes, and Atkinson (1972).

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